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Efficiency of energy use for pregnancy by meat goat does with different litter size

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Abstract

Twenty-four Boer × Spanish does (3 years of age, having kidded once previously and with an initial BW of 42.7 ± 1.2 kg) were used to determine the efficiency of ME utilization for pregnancy (k_{preg}). Six does were nonpregnant and, based on ultrasound determination on day 45 of gestation, six had a litter size (LS) of 1, 2, and 3. However, only 10 of the pregnant does delivered the expected number of kids (3, 4, and 3 with LS of 1, 2, and 3, respectively). Does were fed a diet of approximately 50% concentrate in accordance with assumed maintenance plus pregnancy energy requirements based on estimated nonpregnancy tissue BW and LS. Recovered energy (RE) was determined by subtraction of energy expenditure (EE; respiration calorimetry) near days 80, 100, 120, and 140 of gestation from ME intake (MEI). RE was assumed attributable to pregnancy tissues (fetus, fetal fluids and membranes, uterus, and mammary gland), and ME used for pregnancy (ME_{preg}) was estimated by subtracting ME_m determined with nonpregnant goats from MEI by those pregnant. For does with actual LS equal to that expected, the no-intercept equation for the regression of RE against ME_{preg} was: $RE = ME_{preg} \times 0.252$ (S.E. = 0.030; $R^2 = 0.64$), indicating a k_{preg} of 25%. A regression including LS (1 versus 2 or 3) suggested greater k_{preg} for LS of 1 (40.2 ± 5.6%) versus 2 or 3 (20.5 ± 3.2%). Regressions for goats with LS different from expected suggested positive effects of use of energy mobilized from nonpregnancy tissues on k_{preg} and of use of dietary ME for energy accretion in nonpregnancy tissues on the efficiency of whole body ME utilization. In conclusion, the average efficiency of ME use for pregnancy regardless of LS in goats was near 25%, which when considering the expected proportion of all pregnancy tissues attributable to fetal or conceptus tissues implies an energy requirement for pregnancy of goats similar to common recommendations for sheep and cattle.

Keywords: Goats; Energy; Pregnancy

1. Introduction

The energy requirement for pregnancy represents a considerable proportion of total needs of reproducing ruminants. Though the efficiency of ME use for true fetal growth is not markedly different from that for gain by growing ruminants (Bell, 1986), with consideration of

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ME use for maintenance and development of all tissues involved in pregnancy the efficiency of energy use is quite low (ARC, 1980; Bell, 1993).

NRC (1981) recommended an additional 318 kJ/kg $BW^{0.75}$ of ME in the last 2 months of gestation for goats, and a 20% increase was proposed for multiple births. AFRC (1998) based pregnancy ME requirements of goats on a k_{preg} of 13.3% (ARC, 1980), sheep tissue composition data, mean birth weights from dairy and fiber-producing goat kid data sets, and use of a Gompertz equation. NRC (1985) recommendations for the net energy requirement of pregnancy of sheep were based on reports of Rattray et al. (1974b) for the gravid uterus (plus contents) and mammary gland. CSIRO (1990) predicted a ME requirement for maintenance and development of the gravid uterus for cattle, sheep, and goats with a Gompertz model adapted from that of ARC (1980). Sahlu et al. (2004) proposed a system to predict the ME requirement for pregnancy (ME_{preg}) of goats in late gestation, based on Eq. II of Koong et al. (1975) developed for sheep to predict fetal weight at different days of gestation, sheep data of Rattray et al. (1974b) to predict total energy and protein in all pregnancy tissues, including the mammary gland, and a k_{preg} of 13.3% (ARC, 1980).

In contrast to the findings outlined above, Voicu et al. (1993) reported a higher efficiency of ME use for growth of the fetus and fetal membranes of goats of 21%. Furthermore, based on these data Drochner et al. (2003) proposed an efficiency of ME use for conceptus growth of 30%. In this regard, because of the small number of studies with goats and some ME_{preg} recommendations based on data from other ruminant species, this experiment was conducted to evaluate effects of litter size on the efficiency of energy utilization for pregnancy in meat goats.

2. Materials and methods

2.1. Animals and diet

Twenty-four Boer × Spanish does, 3 years of age and having kidded once previously, were used in the study, with 18 pregnant and 6 nonpregnant. Initial BW on day 64 of gestation was 42.7 ± 1.2 kg. Based on an ultrasound determination at approximately 45 days of gestation, there were 6 does each with 0, 1, 2, and 3 fetuses. On day 64, does were placed in 1.05 m × 0.55 m elevated pens with plastic-coated expanded metal floors and nipple waterers, where they resided at times other than during nutrient balance and gas exchange determinations. Does were allocated to six sets, each consisting of one doe expected to have a litter size (LS) of 0, 1, 2, and 3.

Table 1
Composition of the diet fed to pregnant meat goat does

Item	DM (%)	ME concentration (MJ/kg); NRC (1981)
Ingredient		
Cottonseed hulls	35.63	6.82
Ground alfalfa hay	15.10	9.08
Ground corn	21.16	13.47
Soybean meal	21.14	13.31
Molasses	2.10	11.97
Dried molasses product	2.63	9.57
Dicalcium phosphate	1.12	
Vitamin premix[a]	0.56	
Trace mineralized salt[b]	0.56	
Chemical composition		
Ash	6.5	
CP	18.5	
NDF	44.0	

[a] Contained 2200 IU/g Vitamin A, 1200 IU/g Vitamin D_3, and 2.2 IU/g Vitamin E.
[b] Contained 95–98% NaCl and at least 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.011% Co, 0.007% I, and 0.005% Zn.

On days 70, 92, 113, and 132 of gestation, doe sets were moved sequentially to metabolism crates equipped with head-boxes similar to those used later for gas exchange measurement, with water available at all times.

An approximately 50% concentrate diet (Table 1) was fed twice daily at 08:00 and 15:00 h. Nonpregnant does were offered an amount of feed adequate for maintenance (ME_m), which was assumed 438 kJ/kg $BW^{0.75}$ (AFRC, 1998). The dietary ME concentration assumed, based on ingredient proportions and ME concentrations of NRC (1981), was 10.0 MJ/kg DM. Pregnant does were also fed at this level of intake from days 64 to 90 of gestation. On days 91, 101, 111, 121, and 131 of gestation, the level of intake was increased in accordance with assumed LS and requirements for pregnancy described by Sahlu et al. (2004), which were based on predicted birth weights, the Eq. II sheep fetal growth curve of Koong et al. (1975), and mass and composition of sheep pregnancy tissues (fetus, fetal fluids and membranes, uterus, and mammary gland) on different days of gestation of Rattray et al. (1974b). However, only 10 of the pregnant does had the expected LS (3, 4, and 3 with LS of 1, 2, and 3, respectively). Five does had less kids than expected and, thus, were fed more than desired, and three does had a greater number of kids than assumed and were fed less than assumed required.

2.2. Nutrient balance

Feces and urine were collected four times during the gestation period over 6-day periods of days 75–80, 95–100, 115–120, and 135–140. Feces was collected in wire-screen baskets placed under floors of the crates and urine through funnels into plastic buckets containing 20 ml of a 10% (v/v) solution of sulfuric acid. Subsamples (15%) of feces and urine were collected daily and stored at −20 °C until later analyses. Feed, ort, and fecal samples were dried in a forced-air oven at 55 °C for 48 h and ground in a Willey mill to pass a 1 mm screen. Feed and ort samples were analyzed for DM, ash, N, gross energy (bomb calorimetry; GE) (AOAC, 1990), and NDF (filter bag technique; ANKOM Technology Corp., Fairport, NY), and fecal samples were analyzed for DM, ash, GE, N, and NDF. Urine samples were assayed for DM (lyophilization), and N and GE concentrations were determined with lyophilized samples.

2.3. Gas exchange

Gas exchange measurements were performed the last 2 days of the nutrient balance determination periods, with does moved into a calorimetry room equipped with metabolic crates and head-boxes. Also, after the last measurement period, gas exchange was determined with the nonpregnant does on the third and fourth day of fasting. Oxygen consumption and production of carbon dioxide and methane were determined by using an open-circuit respiration calorimetry system (Sable Systems, Las Vegas, NV) with four head-boxes placed in a calorimetry room. Oxygen concentration was analyzed using a fuel cell FC-1B oxygen analyzer (Sable Systems). Carbon dioxide and methane concentrations were measured using infrared analyzers (FC-1B for CO_2 and MA-1 for CH_4; Sable Systems). Air was first analyzed for CH_4 then for CO_2 and O_2. Prior to the gas exchange measurements in each period, validity and accuracy of expired CO_2 and inspired O_2 flows were checked with alcohol combustion (average 100.6 ± 0.8 and $99.7 \pm 1.1\%$ of expected CO_2 production and O_2 consumption, respectively). Before each measurement periods, analyzers were calibrated with reference gas mixtures (19.5 and 20.5% O_2, 0.0 and 1.5% CO_2, and 0.0 and 0.3% CH_4).

2.4. Calculations and statistical analysis

ME intake (MEI) was calculated as the difference between GE intake and the sum of energy in feces, urine, and methane. EE was estimated based on the Brouwer (1965) equation with oxygen consumption and carbon dioxide and methane production obtained on days of gas exchange and urinary N excretion measurement during both the nutrient balance determinations and fasting periods. k_m was estimated with nonpregnant does at the end of the experiment as the slope of the regression of retained energy (RE) against ME intake. k_m was applied to EE by nonpregnant does at earlier times to estimate ME_m, which was applied to pregnant does as has been previously done with sheep by Rattray et al. (1974a). To determine the amount of the diet needed to meet the ME_m of pregnant does, nonpregnancy tissue BW ($BW_{nonpreg}$) was estimated by subtracting the estimated mass of pregnancy tissue, derived from the method described by Sahlu et al. (2004), from total BW.

The difference between MEI and ME_m was assumed to be ME used for pregnancy (ME_{preg}), and that between MEI and EE was assumed to be RE in pregnancy tissues (RE_{preg}). Hence, energy mobilization from or storage in nonpregnancy tissues was ignored. This assumption was made because BW varies with gut digesta fill. This affects the ability of using $BW_{nonpreg}$ to assess body energy content. With regard to this and because some animals had more kids than expected and some had less, doe data were categorized into three outcome groups based on actual versus expected LS: actual = expected (Group 1), actual > expected (Group 2), and actual < expected LS (Group 3). Group 1 would be expected to store or accrete less energy in nonpregnancy tissues than Groups 2 and 3. Group 2 would be expected to mobilize relatively more energy than other groups to support pregnancy for the greater number of kids than were being fed for. Likewise, Group 3 would be expected to accrete relatively more energy than other groups, since the level of feeding was greater than the pregnancy need. Hence, division into groups was a means of addressing energy mobilization and accretion in nonpregnancy tissues.

Though different pregnancy tissues develop in different periods of late gestation and Freetly and Ferrell (1997) proposed earlier change in EE in support of pregnancy for sheep with LS of 2 versus 1, the efficiency of ME use for pregnancy (k_{preg}) is normally assumed constant throughout late gestation. Thus, RE_{preg} was regressed against ME_{preg} separately for each group with GLM procedures of SAS (1990), with the slope being k_{preg}. Intercepts were not different from zero; therefore, regressions were forced to pass through the origin. In addition, to evaluate potential influences of LS, ADG by nonpregnancy tissues ($ADG_{nonpreg}$) from the previous to the current measurement period, and differences between actual and desired levels of intake, other factors were tested for model inclusion (i.e., LS, ME^2_{preg}, $ADG_{nonpreg}$ and

$ADG^2_{nonpreg}$; ME^2_{preg} and $ADG^2_{nonpreg}$ are to address quadratic effects). Data for different LS were combined when regression coefficients did not differ ($P > 0.05$).

In addition to the aforementioned regression analyses for k_{preg}, other data were first analyzed by a mixed model (Littell et al., 1996) with a repeated measure of measurement period or day of gestation. These data were then analyzed separately for each measurement period by GLM procedures of SAS (1990); however, differences among LS within period are denoted in tables only with a significant ($P < 0.05$) interaction between LS and period. Birth weight data were analyzed by GLM procedures. For Group 1 with equal expected and actual LS, nonpregnant does were included. Differences among means were determined by least significant difference.

3. Results

3.1. Intake and digestion

Digestibility of GE was not influenced by LS, measurement period, or their interaction ($P > 0.05$; Tables 2 and 3). For Group 1 (actual LS equal to that expected), as anticipated there were interactions ($P < 0.05$) between LS and measurement period in DM, GE, and ME intakes. Though methane emission was considerably greater at day 120 versus other times for LS of 2 and 3 of Group 1, the interaction between LS and measurement period was not significant ($P > 0.05$). However, period did influence ($P < 0.05$) methane emission and urinary N excretion for Group 1. For Group 1, energy loss as a proportion of GE intake in urine (4.1, 4.3, and 3.9%; S.E. = 0.22) and methane (4.4, 4.7, and 4.9%; S.E. = 0.28) and dietary ME concentration (10.7, 10.7, and 10.5 MJ/kg DM for LS of 1, 2, and 3; S.E. = 0.198) were similar ($P > 0.05$) among LS. MEI over the entire experimental period averaged 105, 136, 139, and 150% of ME_m (S.E. = 3.3) for LS of 0, 1, 2, and 3, respectively. In most cases feed was completely consumed, but occasionally there were significant feed refusals, particularly in late gestation. For Group 2, MEI averaged 134 and 135% of ME_m (S.E. = 1.8) for LS of 2 and 3, respectively, and for Group 3, average MEI was 124 and 139% of ME_m (S.E. = 5.0) for LS of 1 and 2, respectively. As projected, EE by Group 1 does was affected by a LS × measurement period interaction ($P < 0.05$), although the interaction was not significant for Groups 2 or 3 ($P > 0.05$). RE for Group 1 was affected ($P < 0.05$) by LS and measurement period but not by their interaction ($P > 0.05$).

3.2. k_{preg}

EE by nonpregnant does when fasting was 4.66 MJ/day (S.E. = 0.659) and k_m was 75% (S.E. = 1.5). The only factor having significant influence in the regression of RE_{preg} for Group 1 does was ME_{preg} without (Eq. 1) and with consideration of LS (Eq. 2; Table 4). Based on Eq. 1, k_{preg} for all LS was 25%. Regression coefficients for LS of 2 and 3 were not different and, thus, these observations were pooled. k_{preg} from Eq. 2 was 40.2% for LS of 1 compared with 20.4% for LS of 2 and 3 ($P < 0.05$), with consideration of LS resulting in a decrease in the root mean square error.

In contrast to does of Group 1, for Groups 2 and 3 some of the additional factors tested had significant effects in regressions and increased variation accounted for. For does of Group 2 (actual LS greater than expected), based on the regression against ME_{preg} alone (Eq. 3; Table 4), k_{preg} was numerically greater than for Group 1. The regression coefficient for $ADG_{nonpreg}$ was negative both without and with consideration of LS (Eqs. 4 and 5, respectively). In contrast to similar k_{preg} for LS of 2 and 3 for Group 1 does, k_{preg} was greater for LS of 3 versus 2, although the R^2 of the equation considering impact of LS was only slightly greater than that without LS in the model (Eq. 5 versus Eq. 4).

k_{preg} for does of Group 3 (actual LS less than expected) was similar to that for Group 2 does (Eq. 6; Table 4) and also slightly greater than that for does of Group 1. k_{preg} was similar for LS of 1 and 2 in contrast to findings for Group 1. Both ADG_{preg} and ADG^2_{preg} had significant effects when included in the regression, with positive and negative coefficients, respectively (Eq. 7), resulting in an appreciable increase in explained variability compared with regression against ME_{preg} alone.

4. Discussion

4.1. k_{preg} estimates of this experiment

The lack of significant effects of $ADG_{nonpreg}$ and $ADG^2_{nonpreg}$ in the regression of RE_{preg} against ME_{preg} for Group 1 (Eq. 1) suggests that most RE was RE_{preg}. But, this could also reflect an inaccuracy of $ADG_{nonpreg}$ in reflecting change in nonpregnancy tissue energy because of influences of variable gut digesta fill and(or) energy concentration in tissue accreted or mobilized. The significant difference in k_{preg} between LS of 1 versus 2 and 3, coupled with numerically greatest RE at day 140 for LS 1, imply that the level of MEI for LS of 1 may

Table 2
BW, feed intake, and energy measures in meat goat does with actual litter size equal to that expected

Item	Day of gestation[a]	Litter size							
		0	S.E.	1	S.E.	2	S.E.	3	S.E.
n		6		3		4		3	
BW (kg)	80	34.3c	1.31	41.0b	1.86	44.2ab	1.20	46.7a	1.86
	100	33.9c	1.29	42.2b	1.82	46.1ab	1.58	47.8a	1.82
	120	34.3c	1.10	45.8b	1.65	51.6a	1.35	52.9a	1.56
	140	34.4c	1.33	50.1b	1.89	56.8a	1.63	58.7a	2.31
Birth weight (kg)									
Total		–	–	4.30c	0.266	7.37b	0.231	9.39a	0.266
Mean		–	–	4.30a	0.192	3.68b	0.167	3.13c	0.192
GE digestion (%)	80	66.0	1.88	68.8	2.66	68.5	2.30	63.5	2.66
	100	68.5	0.80	67.9	1.14	68.3	0.98	67.4	1.14
	120	66.4	2.05	65.1	2.89	64.7	2.51	66.1	2.90
	140	68.0	3.61	61.9	5.11	64.8	4.42	65.3	2.47
DM intake (g/day)	80	0.63b	0.023	0.71a	0.032	0.74a	0.028	0.79a	0.032
	100	0.63c	0.023	0.73b	0.033	0.78ab	0.028	0.86a	0.033
	120	0.64c	0.019	1.03b	0.027	1.18a	0.024	1.23a	0.027
	140	0.64c	0.037	1.29b	0.052	1.27b	0.045	1.46a	0.065
GE intake (MJ/day)	80	11.8b	0.42	13.1a	0.60	13.8a	0.52	14.7a	0.60
	100	11.6c	0.43	13.5b	0.60	14.5ab	0.52	15.9a	0.60
	120	11.8c	0.36	19.1b	0.51	22.0a	0.44	22.7a	0.51
	140	11.9c	0.68	23.9b	0.96	23.4b	0.83	27.1a	0.96
ME intake (MJ/day)	80	6.4b	0.31	7.6a	0.44	8.0a	0.38	7.9a	0.44
	100	6.8c	0.28	7.9b	0.39	8.5ab	0.34	9.1a	0.39
	120	6.5c	0.32	10.9b	0.46	12.2a	0.40	13.0a	0.46
	140	7.1c	0.35	13.5b	0.49	13.6b	0.43	15.7a	0.60
Methane emission (MJ/day)	80	0.75	0.086	0.77	0.122	0.82	0.106	0.68	0.122
	100	0.61	0.065	0.61	0.092	0.75	0.080	0.84	0.092
	120	0.76	0.085	0.86	0.120	1.13	0.104	1.29	0.120
	140	0.54	0.120	0.58	0.155	0.61	0.135	1.11	0.190
Urinary N excretion (g/day)	80	2.21	0.189	1.95	0.268	2.09	0.232	1.86	0.268
	100	1.96	0.186	1.55	0.263	1.61	0.228	1.49	0.263
	120	1.70	0.175	1.50	0.247	1.65	0.214	1.39	0.247
	140	1.60	0.267	1.64	0.377	1.70	0.327	1.12	0.377
Energy expenditure (MJ/day)	80	7.02	0.244	7.53	0.344	7.71	0.298	8.06	0.344
	100	6.16c	0.261	7.55b	0.369	8.04b	0.230	9.19a	0.369
	120	6.24c	0.313	9.26b	0.442	11.31a	0.383	11.50a	0.442
	140	6.43c	0.407	11.13b	0.576	12.90a	0.499	13.82a	0.705
Retained energy (MJ/day)	80	−0.62	0.306	0.09	0.433	0.25	0.375	−0.21	0.433
	100	0.61	0.176	0.36	0.249	0.47	0.216	−0.13	0.249
	120	0.30	0.330	1.60	0.467	0.85	0.405	1.48	0.467
	140	0.52	0.433	2.40	0.612	0.70	0.530	1.92	0.750

Means in a row with different letters (a–c) differ ($P < 0.05$).
[a] Measures near 80, 100, 120, and 140 days of gestation. For nonpregnant does, these days refer only to different periods of measurement, at the same time as for pregnant does.

have been greater than required for maintenance plus pregnancy and that energy storage in nonpregnancy tissue occurred. Hence, the LS difference in k_{preg} between LS may have been overestimated, which is supported by regressions for Groups 2 and 3.

For Group 3 (actual LS less than expected) with MEI providing ME_{preg} greater than the assumed requirement, the positive regression coefficient for $ADG_{nonpreg}$ (Eq. 7) implies greater efficiency of ME use for nonpregnancy tissue energy accretion than for pregnancy. For example,

Table 3
BW, feed intake, and energy measures in meat goat does with actual litter size greater and less than expected

Item	Day of gestation[a]	Litter size (actual > expected)				Litter size (actual < expected)			
		2	S.E.	3	S.E.	1	S.E.	2	S.E.
n		2		1		3		2	
BW (kg)	80	38.3	1.64	48.0	2.32	41.0	2.16	44.4	2.64
	100	40.0	1.90	49.0	2.69	42.2	2.62	45.4	3.21
	120	43.8	2.58	50.8	3.66	47.0	2.25	50.0	2.75
	140	50.0	2.66	55.6	3.76	52.2	2.13	55.7	2.60
Birth weight (kg)									
Total		6.34	0.205	9.22	0.290	3.03b	0.375	6.23a	0.459
Mean		3.17	0.201	3.07	0.144	3.03	0.326	3.12	0.400
GE digestion (%)	80	66.0	1.39	70.0	1.96	71.0	2.12	67.6	2.59
	100	67.6	1.72	67.8	2.43	68.5	2.54	67.0	3.11
	120	62.8	1.81	63.5	2.56	66.1	4.01	65.0	4.92
	140	58.9	4.34	61.1	6.14	66.2	3.77	59.0	4.61
DM intake (g/day)	80	0.69b	0.002	0.80a	0.003	0.67	0.075	0.73	0.092
	100	0.71b	0.002	0.82a	0.003	0.71	0.078	0.78	0.096
	120	0.99b	0.015	1.05a	0.021	1.03	0.100	1.18	0.122
	140	1.28b	0.028	1.29a	0.040	0.14	0.156	1.45	0.191
GE intake (MJ/day)	80	12.8b	0.03	14.8a	0.05	12.4	1.11	13.5	1.72
	100	13.2b	0.03	15.2a	0.45	13.1	1.48	14.5	1.80
	120	18.4	0.28	19.4	0.39	19.0	1.89	21.9	2.31
	140	23.6	0.52	23.9	0.73	21.1	2.86	27.0	3.50
ME intake (MJ/day)	80	7.3	0.28	8.7	0.39	7.5	0.59	7.7	0.72
	100	7.5	0.20	8.7	0.28	7.7	0.98	8.3	1.19
	120	9.9	0.50	10.4	0.71	10.4	0.57	12.4	0.70
	140	12.2	1.47	13.0	2.08	12.4	1.43	14.5	1.76
Methane emission (MJ/day)	80	0.59	0.377	0.94	0.534	0.57	0.173	0.91	0.212
	100	0.88	0.038	0.91	0.054	0.57	0.116	0.84	0.142
	120	0.91	0.028	1.02	0.040	1.09	0.100	0.98	0.123
	140	0.95	0.140	0.62	0.197	0.66	0.274	0.52	0.336
Urinary N excretion (g/day)	80	1.61	0.009	2.33	0.012	2.28	0.223	1.93	0.273
	100	1.57	0.193	1.46	0.273	1.66	0.154	1.29	0.189
	120	1.56	0.080	1.89	0.113	1.69	0.268	1.36	0.328
	140	1.43	0.119	2.15	0.168	1.60	0.275	1.81	0.337
Energy expenditure (MJ/day)	80	7.01	0.061	8.38	0.087	7.21	0.545	8.10	0.668
	100	7.05	0.075	7.98	0.106	7.59	0.795	7.58	0.974
	120	9.00	0.480	8.92	0.679	10.26	0.820	10.37	1.004
	140	11.26	0.865	10.55	1.223	11.50	0.392	12.23	0.480
Retained energy (MJ/day)	80	0.24	0.337	0.31	0.476	0.29	0.156	−0.44	0.191
	100	0.40	0.273	0.69	0.390	0.13	0.284	0.69	0.348
	120	0.90	0.021	1.48	0.030	0.15	0.477	2.00	0.585
	140	0.94	0.603	2.46	0.843	0.90	1.169	2.25	1.432

Means in a row with different letters (a–c) differ ($P < 0.05$).
[a] Measures near 80, 100, 120, and 140 days of gestation.

Rattray et al. (1974a) assumed an efficiency of ME use for nonpregnancy tissue energy accretion of 56%. The negative regression coefficient for $ADG^2_{nonpreg}$ suggests decreasing efficiency of ME use for nonpregnancy tissue energy accretion as the level rose, in accordance with decreasing efficiency of energy use for gain by growing ruminants with increasing MEI (Tolkamp and Ketelaars, 1992). For Group 2 (actual LS greater than expected) with MEI providing ME_{preg} less than assumed required, negative regression coefficients for $ADG_{nonpreg}$ in Eqs.

Table 4
Equations for prediction of retained energy by pregnant meat goat does with different litter size (LS)

Equation	n	R^2	R.M.S.E.[a]	Variable[b]	LS	Regression coefficient	S.E.	P[c]
Actual = expected LS (Group 1)								
1	39	0.64	777	ME_{preg}	1, 2, 3	0.252	0.030	0.01
2	39	0.56	703	$ME_{preg} \times LS$	1	0.402	0.056	0.01
					2, 3	0.205	0.032	0.01
Actual > expected LS (Group 2)								
3	12	0.82	468	ME_{preg}	2, 3	0.300	0.042	0.01
4	12	0.92	325	ME_{preg}	2, 3	0.308	0.028	0.01
				$ADG_{nonpreg}$		−2.209	0.616	0.01
5	12	0.89	287	$ME_{preg} \times LS$	2	0.259	0.036	0.01
					3	0.386	0.048	0.01
				$ADG_{nonpreg}$		−1.460	0.667	0.05
Actual < expected LS (Group 3)								
6	20	0.67	812	ME_{preg}	1, 2	0.318	0.050	0.01
7	20	0.81	652	ME_{preg}	1, 2	0.355	0.046	0.01
				$ADG_{nonpreg}$		5.146	1.567	0.01
				$ADG^2_{nonpreg}$		−0.024	0.007	0.01

[a] R.M.S.E. = root mean square error.
[b] ME_{preg} = ME used for pregnancy; $ADG_{nonpreg}$ = daily change in mass of nonpregnancy tissues (pregnancy tissues = gravid uterus plus mammary gland).
[c] Regression coefficient P-value.

4 and 5 infer a higher k_{preg} for use of mobilized nonpregnancy tissue energy compared with use of dietary ME. Hence, k_{preg} for Groups 1, 2, and 3 together indicate that MEI providing ME_{preg} both above and below that required increased k_{preg}. Likewise, the proposed high level of MEI relative to the assumed ME_{preg} requirement for Group 1 does with a LS of 1 may indicate that the k_{preg} for dietary ME of 25% is an overestimate, with the most appropriate value being between the Eq. 1 k_{preg} of 25% and that for LS of 2 and 3 of 20% from Eq. 2.

4.2. Effects of LS

There are no known energy requirement systems recommending different efficiencies of ME use for pregnancy of females with various LS. Robinson et al. (1980) did not observe a significant effect of LS in sheep on efficiency of ME use for fetal growth. However, small differences between LS of 1 and 2 in sheep of opposite directions were noted by Lodge and Heaney (1970) and Rattray et al. (1974a). Results of the present experiment, though inconclusive, suggest that multiple birth litters can have relatively greater effect on EE to support gestational needs than energy retained in pregnancy tissues compared with single-kid litters.

4.3. Other k_{preg} estimates

Commonly recommended efficiencies of ME use for maintenance and development of pregnancy tissues (e.g., CSIRO, 1990; AFRC, 1993, 1998; NRC, 2000, 2001) are much lower than k_{preg} of the present study. However, these efficiencies pertain to the fetus, conceptus, or gravid uterus. In this regard, by regression analysis Rattray et al. (1974a) estimated k_{preg} (all pregnancy tissues, including the uterus and mammary gland) of 23.6, 20.4, and 30.2% with three different equations based on slaughter data, compared with efficiencies of 12.0–13.5 and 11.6–12.8% for the conceptus (fetus and fetal fluids and membranes) and fetus, respectively. Hence, it would appear that inclusion of the uterus and mammary gland increases estimates of the efficiency of ME use for pregnancy compared with consideration of only the fetus or conceptus. However, data of Rattray et al. (1974a) also indicate that method of determination can have effect, with k_{preg} from a factorial approach and slaughter data of 17.0, 12.1, 21.2, and 18.0% for sheep on day 140 of gestation for a single lamb with high and low MEI and for twins with high and low MEI, respectively.

As noted above, recommendations for energy requirements of pregnancy are somewhat varied in regards to components or tissues considered. k_{preg} of the present study pertain to all components including the mammary gland. In order for accurate usage, estimates of energy accretion in these components are required, such as proposed by Sahlu et al. (2004) based on sheep data of Koong et al. (1975) and Rattray et al. (1974b). However, Sahlu et al. (2004) applied a k_{preg} of 13.3% based on common efficiencies of ME use for fetal or conceptus growth such as of Rattray et al. (1974a), which is less than k_{preg} of the present study as well as of Rattray et al. (1974a); this suggests an overestimation of the ME_{preg} requirement. Nonetheless, many ME_{preg} requirements of Sahlu et al. (2004) are slightly less than predicted by CSIRO (1990).

Efficiencies of ME use for development of pregnancy tissues of Rattray et al. (1974a) have been addressed previously, but there have been many other values presented for sheep and cattle and a small number for goats. Moe et al. (1970) summarized a large number of energy balance/calorimetry studies with dairy cattle and proposed an efficiency of ME use for fetal growth of 11–12%. Based on slaughter data with under-nourished sheep, Sykes and Field (1972) reported an efficiency of ME use for fetal development of 14 and 12% for high and low protein intake treatments, respectively, with calorimetry measures and ewes with single lambs mobilizing nonpregnancy tissue in support of pregnancy. Graham (1964) noted an efficiency of ME use for conceptus development of 18–22% for ewes with single lambs mobilizing nonpregnancy tissue. Jakobsen et al. (1957) reported efficiencies of ME use for development of calf fetus, fetal membranes, and uterus for 10-day periods of days 155–165, 185–195, 193–203, 228–238, and 256–266 of gestation of 8.7, 14.7, 11.3, and 21.3%, respectively. Robinson et al. (1980), with ewes mobilizing nonpregnancy tissue energy and comparative slaughter, observed efficiencies of ME use for fetal development of 10.8–16.3%, with values higher for ewes fed less and mobilizing more nonpregnancy tissue energy than for ones with higher MEI. With slaughter data, Ferrell et al. (1976) reported an efficiency of ME use for beef heifers of 14.0, 12.5, and 12.2% for the gravid uterus, conceptus, and fetus, respectively. Voicu et al. (1993) reported an efficiency of ME use for development of the fetus plus fetal membranes of 21% of goats based on slaughter measures; however, based on these data Drochner et al. (2003) calculated an efficiency of ME use for conceptus formation of 30%.

4.4. Pregnancy tissues considered

An important aspect of any system to address pregnancy ME requirements is mass of the nonpregnancy tissues on which to base the ME_m requirement. Even though EE by nonpregnancy tissues increases during gestation (Freetly and Ferrell, 1997), it is typically assumed constant, with such change addressed by prediction of pregnancy tissue mass at particular times and application of a constant efficiency of ME use for maintenance and energy accretion in all or some pregnancy tissues. For k_{preg} of this study, the sum of mass of body components other than the conceptus and differences in uterus and mammary gland mass between pregnant and nonpregnant states was used to estimate ME_m. In one respect it might be assumed that other systems not including development of the uterus and(or) mammary gland would need to include this mass with that of nonpregnancy tissues and assume the same maintenance requirement per unit $BW^{0.75}$, as well as considering the requirement for energy accretion in the uterus and mammary gland to be the same as for nonpregnancy tissue. However, in practice this may not be most appropriate. That is, if one considers the contribution of energy in the fetus or conceptus to the total in the gravid uterus plus mammary gland, ME_{preg} is similar when based on a k_{preg} such as 25% and energy present in the gravid uterus plus mammary gland compared with an estimate from an efficiency of ME use for fetus or conceptus growth of 13–14% and energy only in these tissues.

5. Summary and conclusions

Based on respiration calorimetry, the average efficiency of ME use for maintenance and development of the gravid uterus plus mammary gland in meat goat does was near 25% regardless of LS, which is in accordance with most common recommendations for sheep and cattle. Although, there was some indication that the efficiency might be greater for LS of 1 than for 2 or 3. Future research should address energy accretion in pregnancy tissues of goats with advancing gestation to which efficiencies of ME use for pregnancy should be applied.

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